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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 47/57

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OPERATION BUFFALO

Target Response Tests

(Co-ordinator : E. R. Drake Seager)

The Effect of Earth Covers on the Resistance of Trench Shelter Roofs

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The Effect of Earth Covers on the Resistance of Trench Shelter Roofs

A. J. Wood

Summary

This report describes the effect of an atomic weapon of about 20 kilotons total energy yield on full-size and model trench shelter roof panels with varying amounts of earth cover. Static tests on both scales were also carried out, and details of all results obtained are given.

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1. Introduction

To obtain information on the effect of earth cover on the resistance to blast of trench shelter roof slabs a series of targets was exposed to Round 1 of Operation Buffalo, which had a total energy yield of about 20 kilotons. These targets were both full-scale and model scale. The model targets were 1/10th full-size, and were included to provide information on the effects of a Megaton weapon.

The slabs were designed by the Ministry of Works [Refs. 1 and 2], the overall dimensions of the full-scale panels being 21 ft x 8 ft x 6 in., and of the 1/10th scale panels 25 in. x 9.4 in. x 0.6 in. The discrepancy between the full-size and model dimensions was caused by differences in the widths of the bearing surfaces; for the full-size slabs this surface was 6 in. all round, giving a clear span of 20 ft x 7 ft, whereas the model slabs were supported on bearing surfaces only 0.5 in. wide, giving a free span of 24 in. x 8.4 in. The corners of the slabs were held down (with reinforcing rods and concrete on the full-size slabs, and special steel clamps on the model slabs) for a length equal to 1/10th of the free span in each direction.

Eight full-size slabs were to be cast, six to be placed in the field, the remainder to be tested statically. Of the six in the field three were at ground level and the other three were buried to give 5 ft of earth cover. Forty-eight models were cast, 36 of which were exposed in the field, 9 models being buried 12 in. below ground level, 9 buried 6 in. deep, 9 buried 3 in. deep and 9 placed level with the surface of the ground.

2. Object of the Investigation

2.1 Full-Size Slabs

The main purpose of this test was to study the effect of earth cover upon the resistance of a reinforced concrete slab to blast loading from a kiloton weapon, and to determine whether static tests could be used to predict performance under blast loading.

2.2 Model Slabs

Again an important part of this test was to study the effect of earth cover on the resistance of the slabs to blast loading from a kiloton weapon and to obtain an assessment of the effect of Megaton weapons on such structures. In addition the experiment was designed to show whether results from static tests could be used to predict the blast resisting performance of this type of structure.

3. Description and Construction of Panels

3.1 Full-Scale

The full-scale panels were rectangular, the dimensions being 21 ft × 8 ft × 6 in. overall. The reinforcement, which was in the bottom face only, consisted of 60 bars $\frac{3}{8}$ in. in diameter at $4\frac{1}{4}$ in. centres across the short span. This gives a percentage reinforcement of 0.431. The only longitudinal steel consisted of 5 bars $\frac{3}{8}$ in. in diameter at 18 in. centres, to act as distribution steel. All reinforcement complied with British Standard Specification No. 785 for mild steel. The concrete cover for the reinforcement was 1 in. This was kept constant by the use of annular bar-spacers.

As can be seen from Figure 1, the thickness of the panel was reduced to 4 in. at the corners, and also the sides were recessed 2 in. This can be seen more clearly in Figure 2 and Figure 3, and was to allow the anchoring bars to be concreted into position. Figure 3 also shows these bars bent over into position, and Figure 4 shows a corner that has been completed.

Again from Figure 1 it can be seen that 20 lifting bars were included in the panel, 10 each side of the centre line, along the span. These lifting bars were $\frac{5}{8}$ in. diameter at 2 ft $1\frac{1}{2}$ in. centres. The distance of the centre line of the bars from that of the panel was 2 ft 3 in.

The concrete mix from which the panels were made was designed to give a compressive strength of 3000 p.s.i. at the time of firing. The mix was in the proportions of 1 part Normal Portland cement (Australian type A, complying with B.S.S. 12) to $3\frac{1}{2}$ parts of coarse aggregate (approximating to $\frac{3}{4}$ in. aggregate, B.S.S. 882) to $3\frac{1}{2}$ parts of fine aggregate (zone 2 crushed stone sand, B.S.S. 882), with a water/cement ratio of 0.875. The materials and design of mix are described in detail in Ref. [3], and grading curves for the aggregates are shown in Figure 5.

The panels were cast in wooden moulds, the base of the mould being lined with building paper and the sides well greased. This wooden mould was placed on a flat concrete slab. The intention initially had been to cast direct on to the concrete slab using only building paper as the base. However, it was found that with the paper alone the adhesion was high, and it was necessary to introduce the wooden base. The reinforcing mat was made up outside the mould, and placed in position just before casting.

Mixing was carried out using a weigh-batching machine and a 10/7 freefall mixer. Compaction was effected with a high frequency poker vibrator. From every second mix, two 6 in. control cubes were cast, and in addition, from every fourth mix a 4 in. × 4 in. × 36 in. control beam was made. Each panel needed about 16 mixes to fill it, and the position of each mix was noted as it was placed (Figure 6). As the strength of the concrete at the time of firing (estimated at 10 to 14 weeks after casting) was to be only 3000 p.s.i. the concrete was of very low strength for some time after it had been cast. The panels were therefore allowed to harden for as long as possible before being moved to the storage area. However, this time was a maximum of 7 days, and it was necessary to add support longitudinally before lifting the panel as there was very little longitudinal reinforcing actually in the panel. Therefore two 12 in. × 6 in. R.S.J.'s were tied to the panel, using ¼ in. diameter steel wire rope, by means of the lifting bars which had been cast into the panel. Two lifting eyes were bolted to each of the R.S.J.'s and the panel was then lifted using chain brothers. The arrangement for tying down the R.S.J.'s and positions of the lifting eyes can be seen in Figure 1.

3.2 Model Scale

The dimensions of the 1/10th scale model panels were 25 in. × 9.4 in. × 0.6 in. The reinforcement across the span consisted of 63 wires 0.036 in. in diameter (20 S.W.G.) at 0.4 in. centres, on the bottom face only. This gave a percentage reinforcement of 0.428. The only reinforcement along the span was distribution steel consisting of 6 wires of 20 S.W.G. at 1.66 in. centres. The cover on the reinforcement was 0.1 in. Details of the slab can be seen in Figure 7.

The panels were cast with a mortar, the "sand" being crushed limestone. All the sand was graded on a vibrating screen, that portion retained on a B.S. No. 100 mesh and passing a B.S. No. 7 mesh being used. A mean grading curve can be seen in Figure 5. The proportions of the mix were 1 part Normal Portland cement (type A) to 4½ parts of sand, with a water/cement ratio of 0.875. This mix, like that for the full-size panels, was designed to give a compressive strength of 3000 p.s.i. at the time of firing [Ref. 3]. The mix was weighed in a laboratory scale and mixed in a Cumflow pan-type mixer of 1¼ ft^3 capacity.

The panels were cast in wooden moulds (Figure 8) in batches of six, a total of eight batches being cast. With each batch of six, which was made from one mix, one control beam 4 in. × 4 in. × 36 in. and three 4 in. cubes were cast from the same mix. Both the panels and controls were compacted on a vibrating table.

The panels were allowed to harden for about 48 hours before being demoulded, and immediately after demoulding were immersed in water for curing. Curing was continued for about 8 weeks. Before the panels were placed in the field they were thoroughly washed with fresh water (salt water having been used for curing) and the undersides whitewashed. This was done so that any fine cracks caused by the blast could be photographed more easily.

4. Field Placing

The slabs were positioned in the field from information obtained in the United Kingdom [Ref. 4].

4.1 Full-Size Slabs

Eight full-size slabs were cast. They were supported on a strip 6 in. wide along each edge. The support was made up of reinforced concrete beams resting on top of mass concrete retaining walls. The dimensions of the beams and walls were such that there was a cavity at least 3 ft deep beneath the panel. The whole arrangement can be seen in Figure 1. To ensure that the slabs were in fact bearing evenly along each edge a layer of soft mortar was placed along the supporting surfaces before the panel was placed in position. So that the panel did not key in any way to the supports, a strip of greased building paper was placed on the bearing surfaces. The panel was positioned and the corners of the panel were then tied down to the supports by means of anchor bars. These anchor bars ($\frac{1}{2}$ in. in diameter) had been grouted into the supports before the panel was placed in position. When the panel had been placed, they were bent over the corners into the portion of the panel which had been specially recessed (Figure 3), and then the recess was filled with mortar to the level of the panel (Figure 4). When the bedding mortar had hardened, the $\frac{1}{2}$ in. wide gap between the side of the panel and the supporting beam was filled with a bituminous sealing compound. This gave an airtight plastic joint all round the panel.

Three of the panels exposed were level with the surface of the ground and were subjected to maximum pressures of 21.6, 14.5 and 10.3 p.s.i. Figure 9 shows a panel in position. Three further panels were exposed at 27, 17.9 and 12 p.s.i., these being 5 ft below ground level and covered with earth to ground level. The damage expected at these ranges was heavy, moderate and light respectively. At the higher pressure levels the blast wave was not of the usual sharp-fronted type and the pressures given are the maximum values recorded.

Unfortunately, the panels with earth cover were all cracked slightly during handling. The worst of these, at 27 p.s.i., was cracked all across the short span. The other two panels had short cracks in this span.

The deflections of the panels in the surface were measured with a levelling staff and level. Nine positions on the surface were selected, and their levels relative to a fixed position on the curb beam found. This was carried out before and after firing, and thus the deflection caused by the blast calculated. It was assumed that the point on the curb beam did not move. To have attempted to make an absolute measure of the deflection, using a bench mark out of reach of air or ground shock, would have been unnecessary and impracticable.

The deflections of the panels with earth cover were measured from underneath using a builder's level, a rigid datum and a scale. This arrangement can be seen in Figure 10. The datum was rested on the mass concrete walls, and levelled using the builder's level. The measurements were then recorded using a flexible steel rule. The points at which measurements were taken coincided as nearly as possible with those positions at which levels were taken on top of the panel before firing (9 points in all), and together with the measurements against the curb beam made a total of 15 measurements (see Figure 10). From these measurements the deflections of the slabs were calculated.

4.2 Model Slabs

The panels were placed on steel box supports, the boxes being made of ½ in. steel plate. The inside dimensions of the boxes were 24 in. × 8.4 in. × 8.4 in. deep. The ½ in. wide supporting surfaces, formed by the sides of the box, were machined flat. So that the corner clamps could be secured, 2 in. × 1½ in. × 3/16 in. angle-iron was bolted round the top of the box. A sketch of the box can be seen in Figure 11. To simulate the corner conditions of the full-size slab, the corners of the model were clamped down with a special clamp which, like the full-size corner condition, restrained the panel for 1/10th of the span. A detail of the clamp also appears in Figure 11. To avoid clamping the panel down so tightly that high stresses were induced, the bolts on the clamps were all only finger-tight.

Unfortunately, owing to a fault which developed in the mould, the panels were all hogging, and therefore to ensure that the panels were supported all along their edges a mix of approximately equal quantities of cement and dune sand, with enough water to give a very workable mix, was placed along the supporting surfaces of the steel boxes. The panel was then placed into position and pressed down firmly. The clamps were fitted and tightened immediately. It was assumed that the whitewash on the panels would prevent bonding between the box and the slabs by the new mortar.

The model panels were all similar but had varying amounts of earth cover. These amounts were specified as 3 in., 6 in. and 12 in. A series was also exposed without cover. Figure 12 shows a panel in the surface ready for firing. The table below details the maximum pressures at which the panels were exposed and the amount of earth cover, together with the amount of damage expected.

Depth of Earth Cover, in.	No. of Models at Each Distance				
	1	2	3	2	1
	Pressure, p.s.i.				
0	8.0	10.3	13.2	17.9	21.6
3	9.0	11.1	14.5	17.9	23.8
6	10.3	13.2	17.9	21.6	27.0
12	12.0	17.9	21.6	27.0	33.5
Damage Expected	None	Light	Moderate	Heavy	Destroyed

The deflection measurement was made with a rigid "bridge" measuring device, incorporating a dial gauge graduated in 0.001 in. to read up to $2\frac{1}{2}$ in. A reading was taken before and after firing, and the deflection calculated. The measuring device was checked before and after firing on a surface plate. The 1, 2, 3, 2, 1, distribution was adopted to economize on the number of panels exposed. The distribution was weighted in this way to give the greatest number of panels at the distance where moderate damage was expected.

A damage analysis from sketches and photographs of crack patterns was required, together with a measure of the residual central deflection. The residual central deflection was required as in this type of panel it was often the only real indication that damage had occurred.

5. Static Tests

5.1 Full-Scale

Two full-scale panels were to have been tested statically, but when lifting one of the panels soon after casting, the crane was not powerful enough to be able to slew the panel on to the transport vehicle, and when the panel was put on the ground it broke into two pieces. This panel could not be replaced, and thus only one was tested.

The panel was set up in a heavy R.S.J. reaction frame, supported on a frame made up of R.S.J.'s. Load was applied through 16 hydraulic jacks and a beam load-spreading system, terminating in 128 wooden feet 2 in. in diameter. The rig and supporting frame is shown in Figure 13. As in the field, a layer of soft mortar was placed on the supporting surfaces before the panel was placed in position, and a strip of greased paper separated the supporting from the bearing surfaces.

During the test, simultaneous readings of load, time and central deflection were taken, this latter being measured with a dial gauge graduated in 0.001 in. to read up to 12 in. Photographs were taken of the development of the crack pattern during the test.

The 6 in. control cubes were crushed to give the compressive strength of the concrete in each panel. The modulus of rupture was derived by applying the theory of simple bending to the results obtained by loading the beam to failure under a two-point loading system in an Avery Universal testing machine.

5.2 Model Scale

The machine used for statically testing the control panels was a Macklow-Smith 200-ton compression testing machine, fitted with a special 20-ton poise, enabling a load of 0.001 tons to be recorded. As in the full-size test, the load was applied to the panel through a beam load-spreading system, terminating this time, however, in 32 wooden loading blocks each 1 in. in diameter. The central deflection of the panel was measured with a dial gauge of 1 in. travel, graduated in 0.001 in. divisions. Simultaneous readings of load, deflection and time were taken throughout the test.

The panel was supported on an angle-iron frame, designed so that the panel was supported on a ½ in. wide strip all round the edges, and the corners were restrained with clamps identical to those used in the field. The whole arrangement ready for testing can be seen in Figure 14. Also, to simulate the field conditions and to ensure all-round support, the panel was bedded on to the frame with a sand-cement grout, as described in Section 4.2.

As has been stated earlier, the panels were cast in eight batches of six. From seven of these batches, five from each batch were tested in the field, the remaining one being statically tested in the laboratory. From the eighth batch only one panel was needed in the field to make a total of 36. One from this batch was tested statically, giving a surplus of 4 panels.

As some of the full-size panels had been cracked before firing, it was decided to crack these surplus models in the same way as the full-size panels were cracked, but rather more severely, and to carry out static tests. From the results it was seen that there was no appreciable difference in strength between the cracked and uncracked panels.

The compressive strength of the mortar was measured by crushing the 4-in. cubes, and the modulus of rupture was obtained from the beams in the same manner as for the concrete of full-size panels. The ultimate tensile strength of the reinforcing wire was checked by making tests with a Hounsfield Tensometer on samples of wire taken from the panels after static and blast loading tests had been carried out. These wires were very rusty, owing to the action of the salt water used in making the mortar. The results were calculated from the nominal diameter of the wire before casting, and not from the actual diameter of the wire after rusting.

6. Results

The results are shown in Tables 1 and 2. Owing to the fact that the blast wave at the nearer distances was not of the usual sharp-fronted form, the pressures quoted throughout this report are the maximum pressures reached. Figure 15 shows the load/deflection curve for the full-size panel tested statically, and Figure 16 the mean static load/deflection curve for the model panels. Figure 17 shows the load/deflection characteristics of model panels cracked before testing. Figures 18-22 show photographs of damage to full- and model scale panels. Figure 6 details the positions in which the different batches were added in the full-size panels, together with the mean value of the compressive strengths of those mixes from which control cubes were made. Figures 23 and 24 show sketches of the crack patterns of the full-size slabs after firing, and Figures 25 and 26 photographs of typical failures on full- and model scale statically tested panels.

7. Comment on Results

7.1 Effect of Earth Cover on Full-Size Slabs

The effect of the earth cover on the full-scale slabs can be seen in Table 1. It will be noticed that whereas a panel at about 22 p.s.i. with no cover was destroyed, that at 27 p.s.i. with 5 ft of earth cover, whilst being heavily damaged, was not destroyed. From this example it would seem that the earth cover had a considerable effect. However, the panel at $14\frac{1}{2}$ p.s.i. with no cover had a residual central deflection only very slightly greater than that with earth cover at 10 p.s.i. and less than half the deflection of the panel with cover at 18 p.s.i. These points would indicate that the cover had a greater effect at the higher pressures. It will be seen from Table 1 that the mean compressive strength of the statically tested panel was only about 2000 p.s.i. as compared with a value for the field tested panels of 3000 p.s.i. In information not yet published it has been shown that an increase of strength of this order on a 12 in. square unreinforced panel 1 in. thick gives an increase of static strength of about $1\frac{1}{2}$ p.s.i. It is considered that the increase in strength on a full-scale trench shelter roof panel would be of the same order.

7.2 Effect of Earth Cover on Model Panels

Table 2 shows that all panels were destroyed at pressures greater than 22 p.s.i. At 18 p.s.i. the only panels to survive were those with 6 in. of earth cover, and these were very near to collapse. Those panels with 3 in. of cover exposed at 14.5 p.s.i. survived, as did all panels exposed to pressures equal to or less than 13 p.s.i.

The damage sustained by these model slabs is comparable with that which full-scale slabs should experience at the same pressure level from a weapon in the kiloton range. The abnormal shape of the blast wave at the nearer distances will have a small but not outstanding effect.

The figures given for the final central deflection are not necessarily a reliable guide to the maximum deflection [Ref. 5], but are included as the only real indication that the panels suffered any damage at all since only four of the surviving panels were visibily cracked, and as can be seen from the photographs in Figures 9-22 the cracking even in these cases was very light.

8. Conclusions

The test showed that the earth cover on the full-size slabs did in fact have the effect of reducing damage, while on the model scale, although the effect was not so marked, it was apparent. The range of damage sustained was, on the whole, satisfactory for both the model and full-scale, which, since the ranges for both types were predicted from model static and blast tests, indicates that this is an acceptable method for predicting performance under blast loading.

References

1. Ministry of Works Drawing No. Q/1036B.

2. Ministry of Works Drawing No. Q/546B.

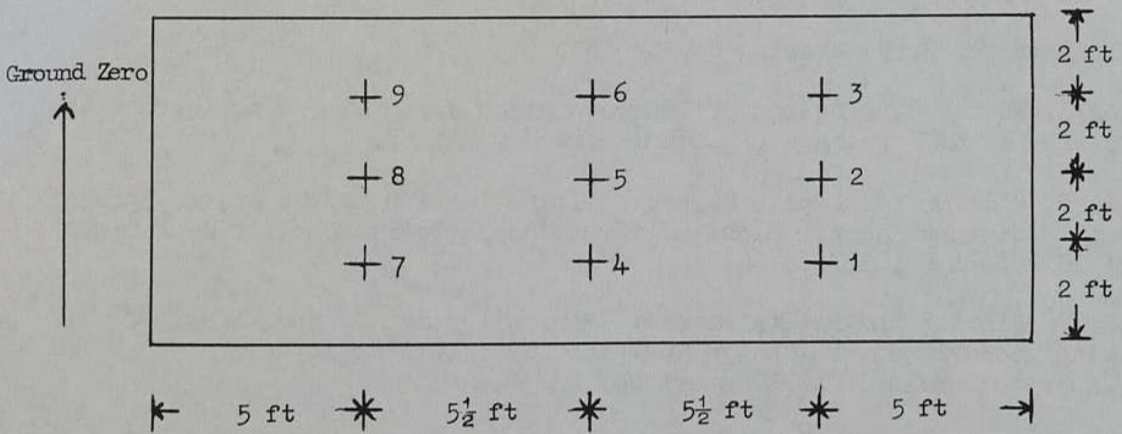
3. A. J. Wood: "The Design of Concrete Mixes Using Limestone Aggregates Available at Maralinga". AWRE Report No. T35/57.

4. T. P. O'Brien and Pepita Pirrie: "Investigation of the Static Strength and Resistance to Air Blast of 1/10th Scale Trench Shelter Roof Slabs". AWRE Report No. E5/57.

5. T. P. O'Brien and Pepita Pirrie: "Investigation of the Effect of Blast Loading on the Damage Sustained by 1/10th Scale Reinforced Concrete Panels". AWRE Report No. E8/56.

TABLE 1

Details of Damage to Full-Size Panels



Plans of Slab: Positions at which Deflections were recorded Shown: +

Panel No.	Maximum Pressure, p.s.i.	Deflection (in.) at Position									Control Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.
		1	2	3	4	5	6	7	8	9		
Panels with No Cover												
2A/A/4	21.6				Destroyed						3230	430
2A/A/6	14.5	0.4	0.7	0.4	0.5	0.9	0.5	0.3	0.6	0.4	3510	449
2A/A/8	10.3	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	2750	347
Panels with 5 ft Earth Cover												
2A/A/2	27.0	0.7	3.5	1.7	2.0	4.1	1.9	1.9	3.4	1.7	3340	346
2A/A/5	17.9	0.8	1.3	0.5	1.0	2.1	0.7	0.7	1.6	0.6	2969	360
2A/A/7	12.0	0.3	0.4	-0.1	0.4	0.8	0.2	0.4	0.7	0.3	2234	320

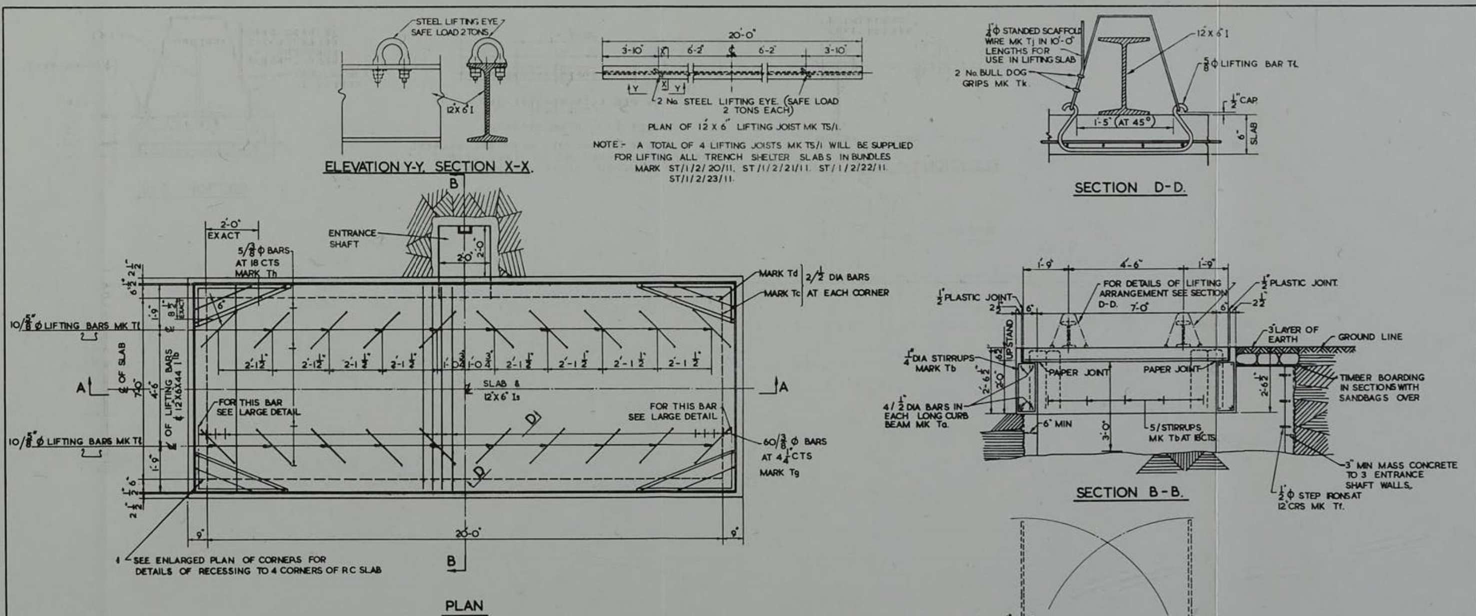
Panel No. 2A/A/3 was tested statically: Max. load = 14.61 p.s.i.
Central defl. at max. load = 1.85 in.
Control cube strength = 2140 p.s.i.
Modulus of rupture = 257 p.s.i.

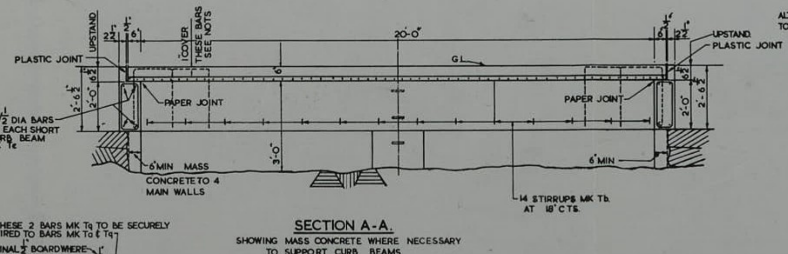
TABLE 2

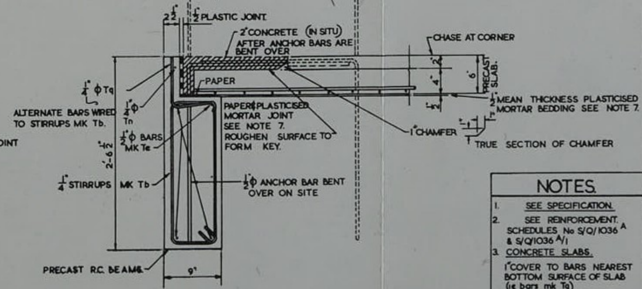
Details of Damage to Model Panels

Panel No.	Maximum Pressure, p.s.i.	Final Central Deflection, in.	Control Panel Characteristics			
			Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.	Max. Static Pressure, p.s.i.	Deflection at Max. Load in.
Panels with No Cover						
2B/B/2	21.6	Destroyed	3330	651	8.56	0.060
2B/A/2)	17.9	(Destroyed	3440	609	9.55	0.043
2B/B/4)		(Destroyed	3330	651	8.56	0.060
2B/D/1)		(0.076	3750	724	8.30	0.039
2B/C/1)	13.2	(0.062	3420	703	10.37	0.049
2B/D/2)		(0.057	3750	724	8.30	0.039
2B/D/5)	10.3	(0.057	3750	724	8.30	0.039
2B/E/5)		(0.056	3290	682	9.00	0.083
2B/F/1	8.0	0.048	3120	609	10.47	0.084
Panels with 3 in. Earth Cover						
2B/C/6	23.8	Destroyed	3420	703	10.37	0.049
2B/C/4)	17.9	(Destroyed	3420	703	10.37	0.049
2B/G/4)		(Destroyed	3230	661	11.14	0.079
2B/E/2)		(0.069	3290	682	9.00	0.083
2B/F/6)	14.5	(0.054	3120	609	10.47	0.084
2B/A/5)		(0.094	3440	609	9.55	0.043
2B/D/4)	11.1	(0.057	3750	724	8.30	0.039
2B/G/2)		(0.062	3230	661	11.14	0.079
2B/H/4	9.0	0.041	3490	598	10.38	0.122
Panels with 6 in. Earth Cover						
2B/E/1	27.0	Destroyed	3290	682	9.00	0.083
2B/D/6)	21.6	(Destroyed	3750	724	8.30	0.039
2B/C/5)		(Destroyed	3420	703	10.37	0.049
2B/C/2)		(0.127*	3420	703	10.37	0.049
2B/G/1)	17.9	(Destroyed	3230	661	11.14	0.079
2B/B/1)		(0.184*	3330	651	8.56	0.060
2B/A/6)	13.2	(0.042	3440	609	9.55	0.043
2B/F/4)		(0.053*	3120	609	10.47	0.084
2B/B/6	10.3	0.040	3330	651	8.56	0.060
Panels with 12 in. Earth Cover						
2B/A/4	33.5	Destroyed	3440	609	9.55	0.043
2B/G/5)	27.0	(Destroyed	3230	661	11.14	0.079
2B/E/4)		(Destroyed	3290	682	9.00	0.083
2B/B/5)		(Destroyed	3330	651	8.56	0.060
2B/E/6)	21.6	(Destroyed	3290	682	9.00	0.083
2B/F/5)		(Destroyed	3120	609	10.47	0.084
2B/A/1)	17.9	(Destroyed	3440	609	9.55	0.043
2B/F/2)		(Destroyed	3120	609	10.47	0.084
2B/G/6	12.0	0.068*	3230	661	11.14	0.079

*Visible cracking







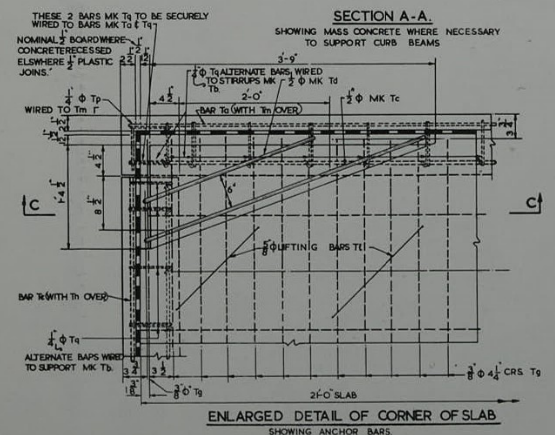


FIG I. DETAILS OF FULL SIZE SLABS.

No 3 SLABS WITH CONCRETE SUPPORTS. MARKED T1-T3
No 2 SLABS WITHOUT CONCRETE SUPPORTS. MARKED T4 - T5

NOTES.

1. SEE SPECIFICATION.
2. SEE REINFORCEMENT SCHEDULES No S/Q/1036 A & S/Q/1036 A/1
3. CONCRETE SLABS. 1" COVER TO BARS NEAREST BOTTOM SURFACE OF SLAB (i.e bars mk Tg)
4. CONCRETE SUPPORTS TO SLABS ONLY 1 1/2" COVER TO 1/2" DIA MAIN BARS.
5. EACH BUNDLE CONTAINS SPARE BARS.
6. THE NUMBER OF BARS SHOWN IN THE REINFORCEMENT SCHEDULES IN THE COLUMN HEADED "No OF BARS IN STRUCTURE" IS THE EXACT NUMBER OF BARS REQUIRED FOR THE PARTICULAR NUMBER OF STRUCTURES STATED ON THE SCHEDULE.
7. PLASTICISED MORTAR FOR BEDDING SLABS. MORTAR 3:1 SAND CEMENT EXCLUDING USE OF LIME. PLASTICISER -1/4 PINT "FEB" TO 1CWT CEMENT. TO OBVIATE EXCESSIVE ABSORPTION & THUS LENGTHEN THE SETTING-TIME; THE DAY BEFOR USE, THE CURBS ARE TO BE DAMPENED & BRUSHED OVER WITH A NEAT CEMENT SLURRY. THE RICH MIX MORTAR WILL ENSURE AN EVEN DISTRIBUTION OF THE BEARING PRESSURES AT SUCH PLACES WHERE THE BEDDING MAY BE THIN.

REF	PARTICULARS	BY	DATE
A	ENLARGED DETAILS OF CORNER OF SLAB. PLAN OF LIFTING JOIST SECTION C-C, D-D, X-X, & Y-Y ADDED & LIFTING BARS ADDED TO PLAN. EXCAVATION REDUCED	JCR	26 10 55
	AMENDMENTS		

TEST STRUCTURES		S.E. BRANCH C.D. SECTION	
FULL SIZE TRENCH SHELTER R.C. SLABS AND SUPPORTS (NO COVER) IN ROCK.		BY	DATE
		DESIGN.	
SCALE: 1/2" & 1 1/2" = 1'-0"	DATE: 10 - 6 - 55	DRAWN.	10.6.55
		TRACED. JP	
		CHECKED. J.W. R.M.	15.7.55
DRG No Q/1036		MINISTRY OF WORKS. LONDON.	

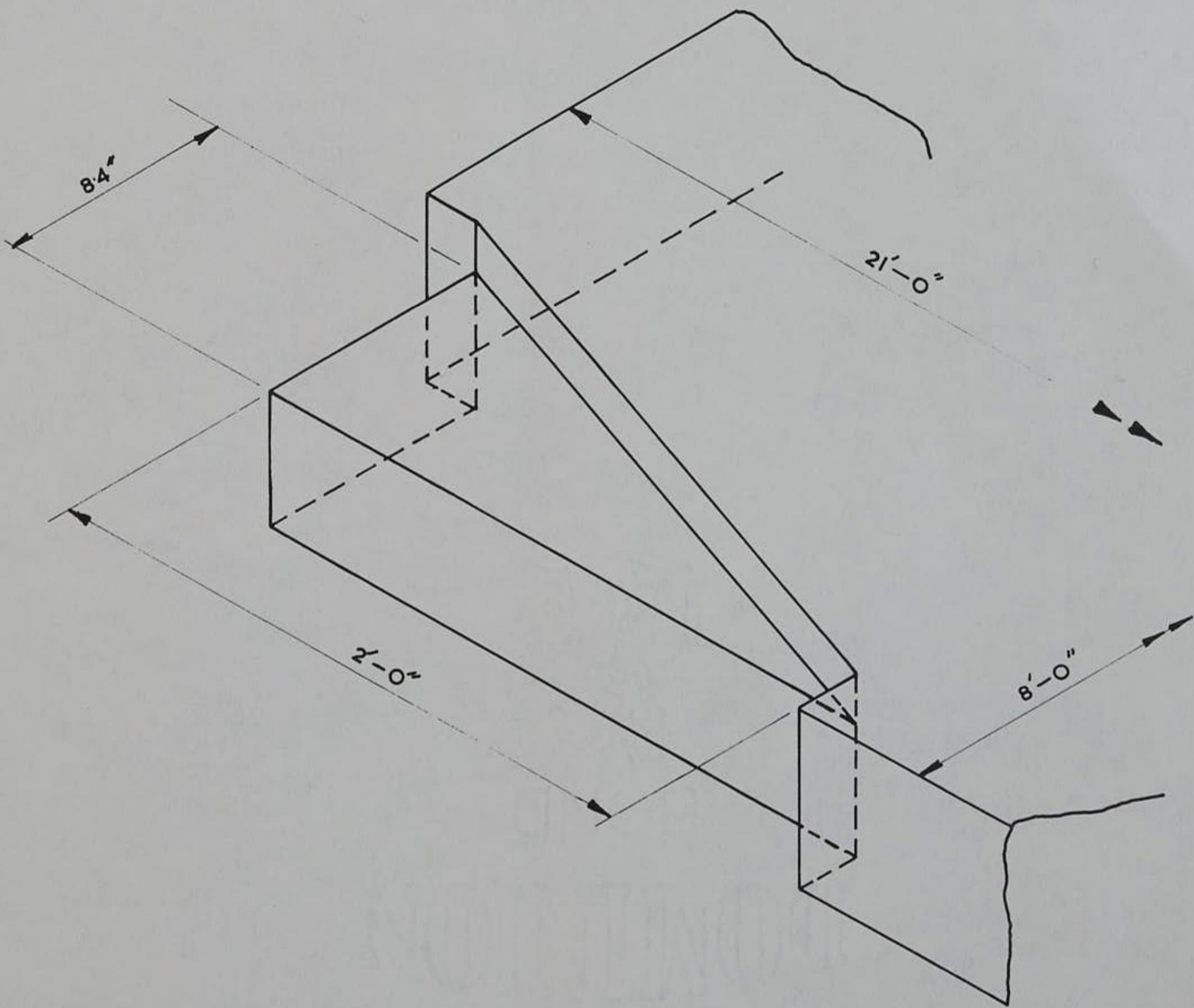


FIG. 2, CORNER DETAIL FULL SIZE SLAB.

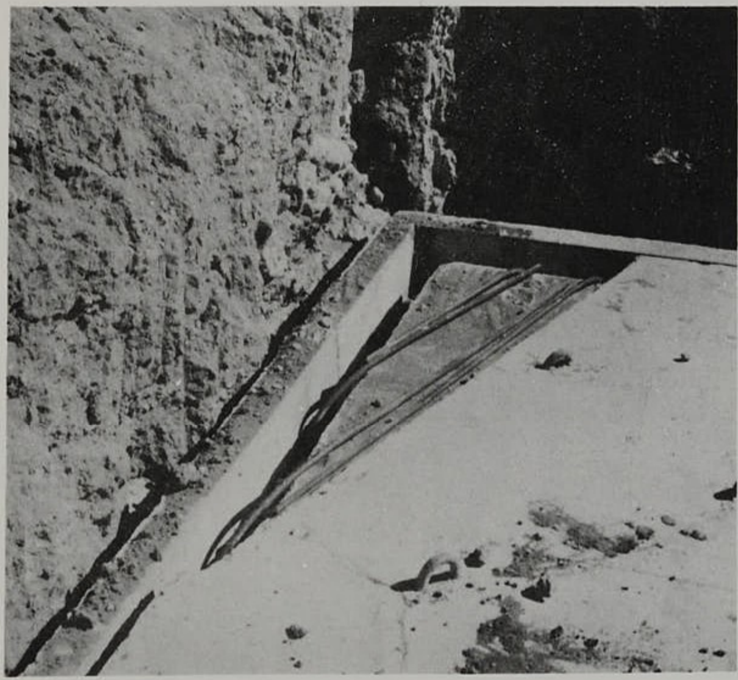


FIG. 3. DETAIL OF CORNER OF FULL SIZE SLAB SHOWING ANCHORING BARS BENT IN POSITION.

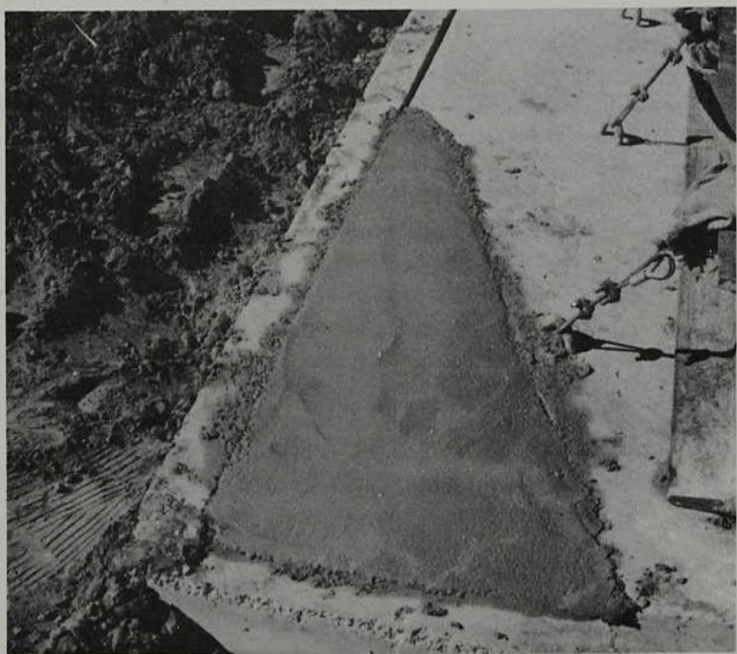


FIG. 4. COMPLETED CORNER FULL SIZE PANEL

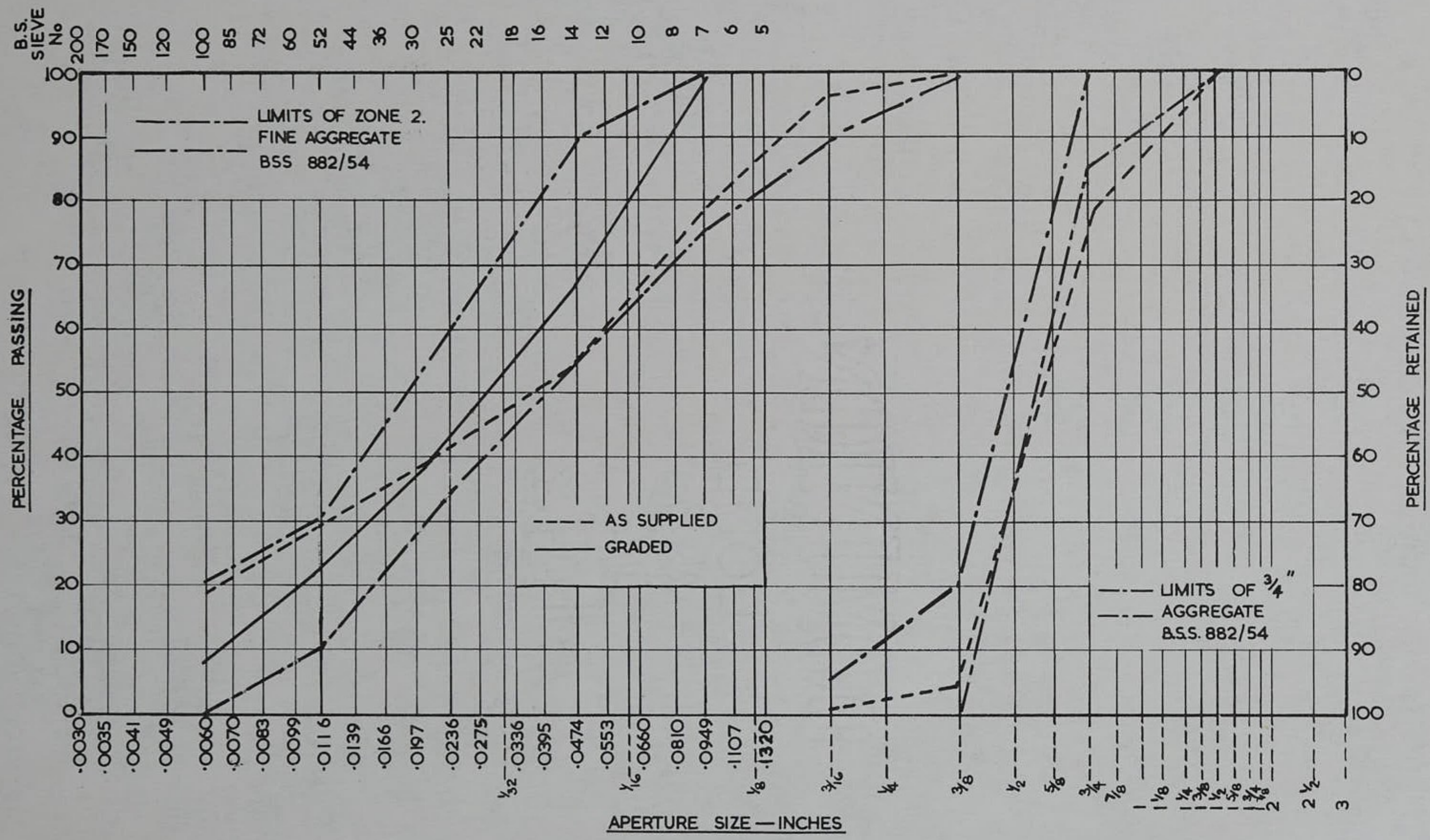


FIG. 5. GRADING OF AGGREGATE.

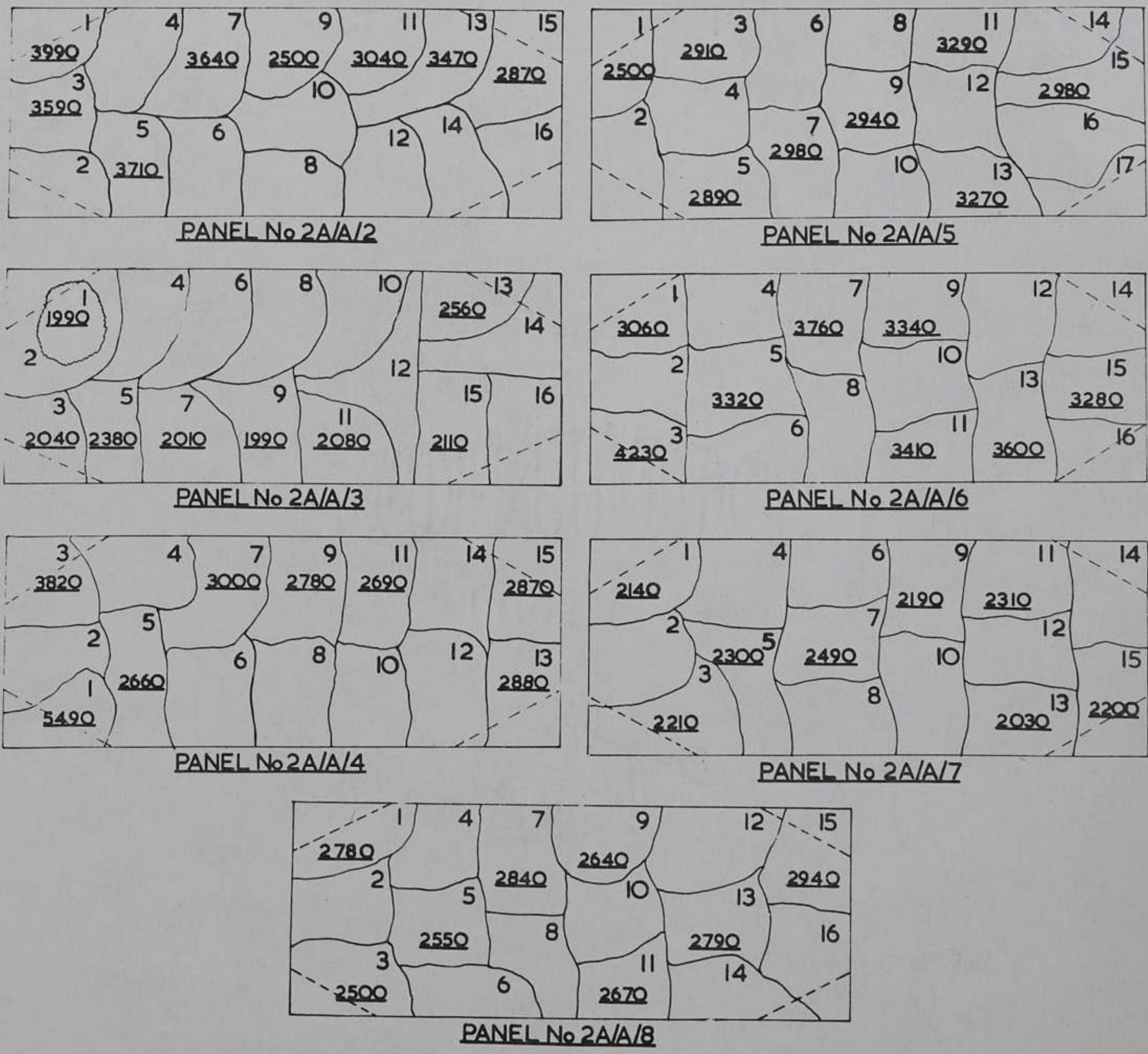


FIG.6. DIAGRAMS SHOWING POSITIONS OF MIXES IN PANELS. FIGURES UNDERLINED SHOW COMPRESSIVE STRENGTHS AS OBTAINED FROM CONTROL CUBES.

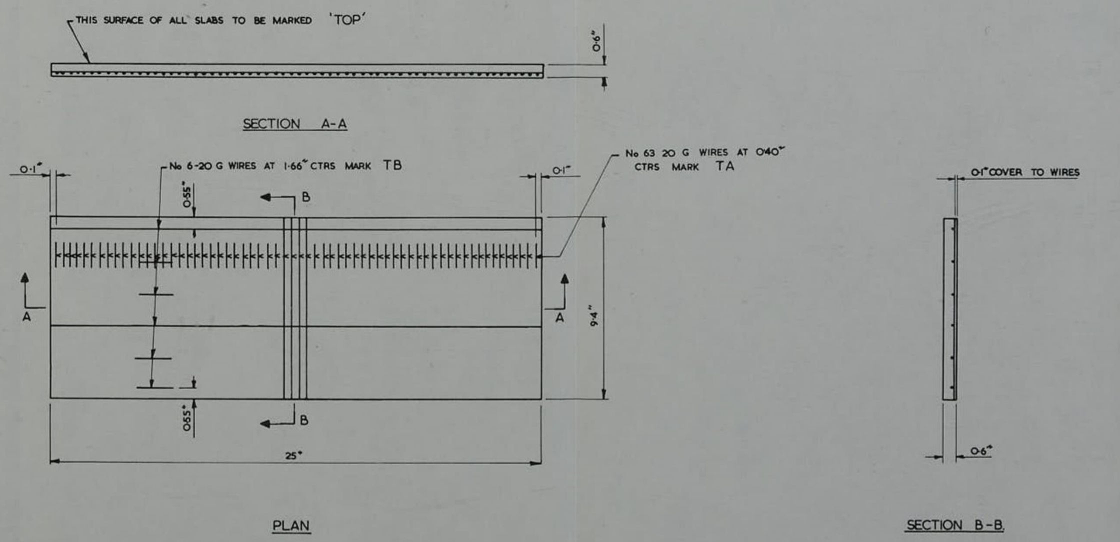
NOTES RE MATERIALS

AGGREGATES.
FINE AGGREGATES SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 882. THE MAXIMUM SIZE OF AGGREGATE SHALL BE THAT PASSING A 1/16" BRITISH STANDARD SIEVE.

CEMENT.
THE CEMENT SHALL BE PORTLAND CEMENT AND SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 12.

REINFORCEMENT.
THE REINFORCEMENT SHALL BE MILD STEEL TO COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 785. THIS MAY BE OBTAINED BY ANNEALING HIGH TENSILE WIRE PROVIDED THAT THE ULTIMATE STRESS AND ELONGATION IS AS DEFINED IN APPENDIX 'A' OF BRITISH STANDARD 785 FOR MILD STEEL.

REINFORCED CONCRETE.
CONCRETE MIX.
THE CONCRETE IS REQUIRED TO HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OF 3,000 LB/SQ.INCH.



FOR DETAIL OF STEEL BOX SUPPORTS SEE DRG No Q/1026

SCHEDULE OF WIRE REINFORCEMENT FOR TOTAL No. OF 39 SLABS			
WIRE MARK	S.W.G. No.	TOTAL No.	WIRE LENGTH (INS.)
TA	20	2457	25·0
TB	20	234	9·4

NOTES.

REINFORCING WIRES TO BE CUT OFF FLUSH WITH EDGES OF CONCRETE SLAB

SEE REINFORCEMENT SCHEDULE ON THIS DRG. FOR TOTAL WIRES TO SLABS MARK M.T.1.–M.T. 39. INCLUSIVE.

SEE "NOTES" MATERIALS ON THIS DRAWING

No. 39. OFF MARKS MT. 1.–MT. 39.

FIG 7 DETAILS OF 1/10TH. SCALE SLABS.

REF.	PARTICULARS	BY	DATE
'A'	No. & LENGTH OF WIRES INCREASED.	V.A.N.	18.7.55

AMENDMENTS.

TEST STRUCTURES	S.E. BRANCH. C.D. SECTION.		
MODEL R.C. TRENCH. SHELTER SLABS		BY	DATE
	DESIGN		
	DRAWN	A.C.	
SCALE 3" TO 1 FOOT / DATE	TRACED	E.J.H.	15.4.57
JOB No.	CHECKD	M.J.	26.4.55
IDENT. No.	STRUCT. FILE No.		
DRG. No. Q/546 B	MINISTRY OF WORKS LONDON		

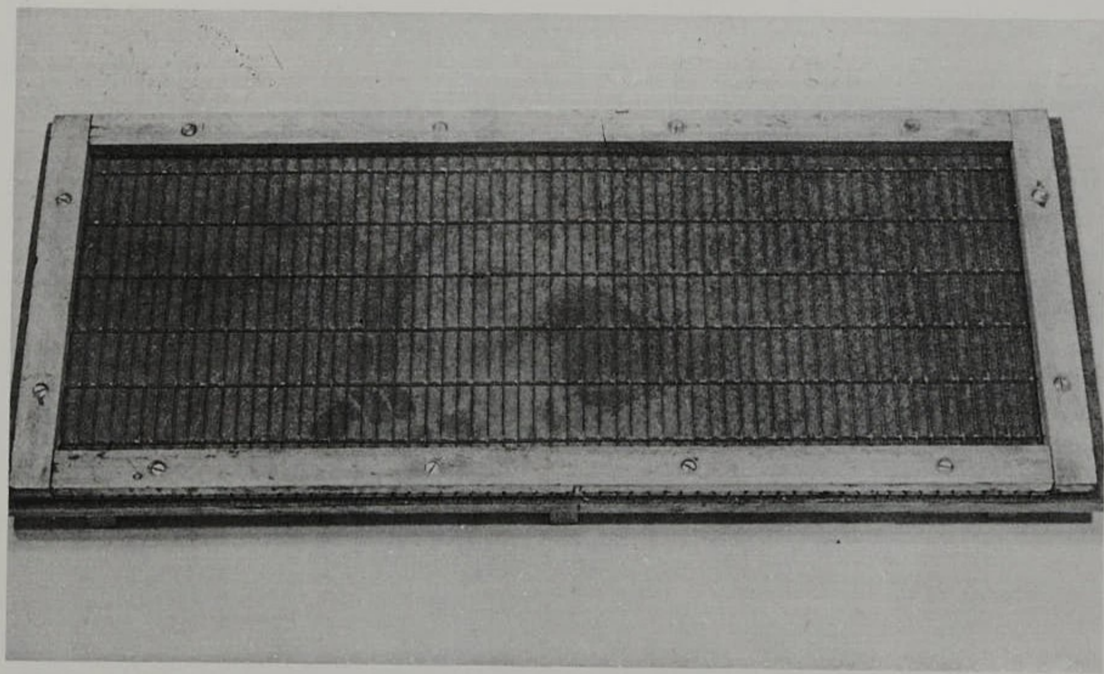


FIG. 8. $\frac{1}{10}$ SCALE MOULD READY FOR CASTING

FIG. 9. PANEL IN SURFACE IN POSITION BEFORE ENTRANCE SHAFT SEALED.

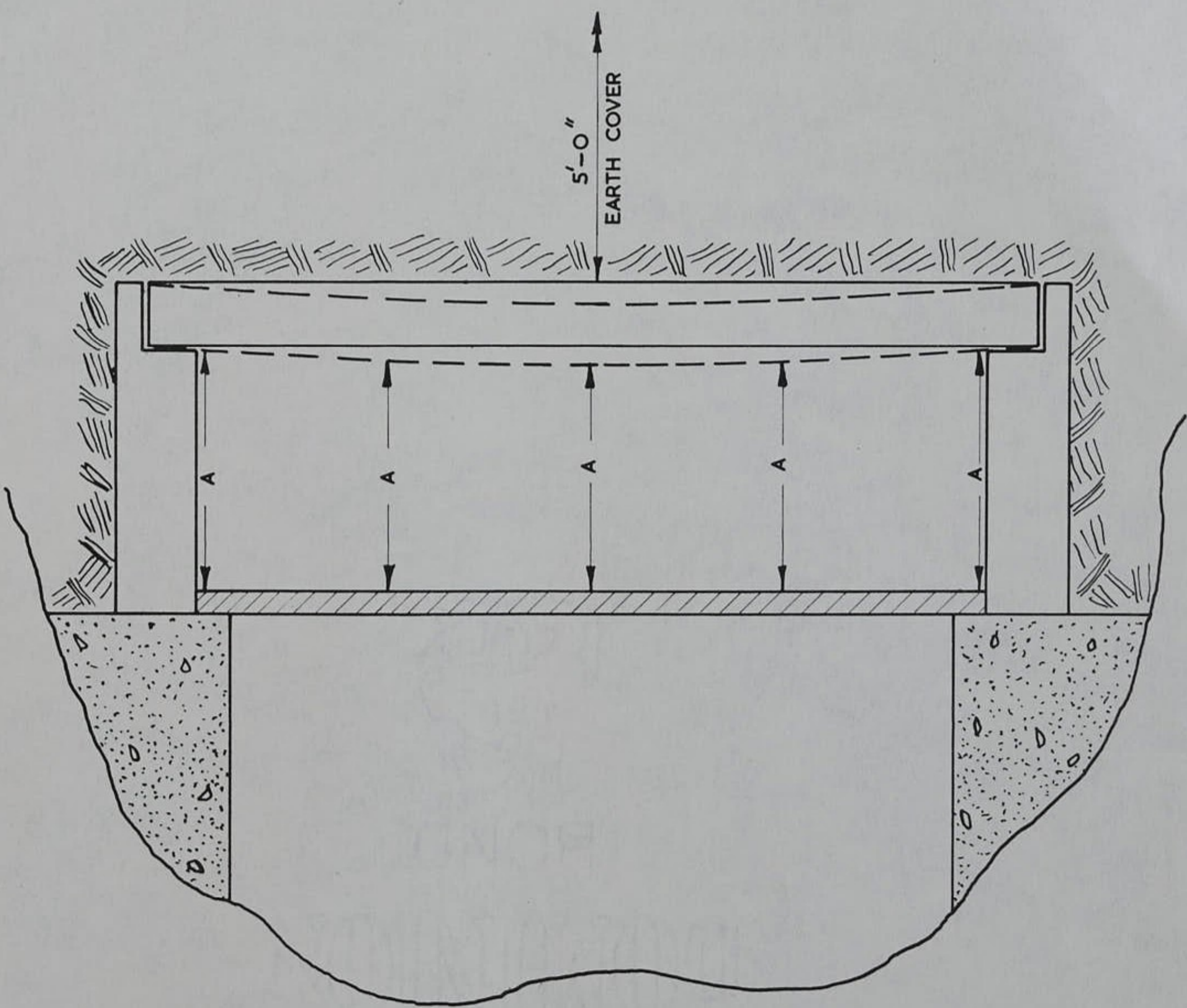


FIG. 10. SKETCH SHOWING METHOD OF MEASURING DEFLECTION OF PANEL WITH 5 FT EARTH COVER. MEASUREMENTS WERE TAKEN AT POINTS 'A'.

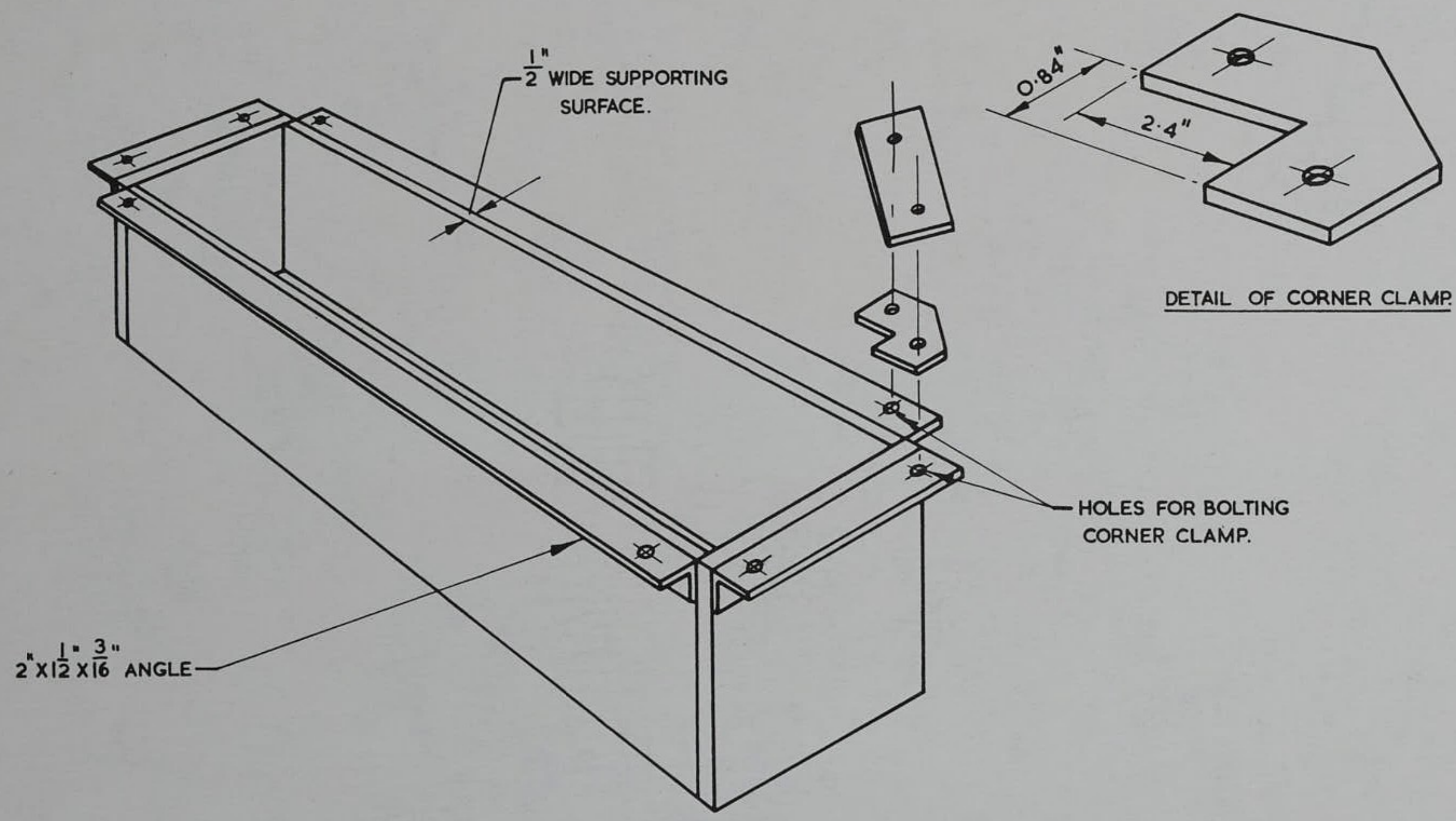


FIG. 11 STEEL BOX SUPPORT FOR MODEL PANEL.

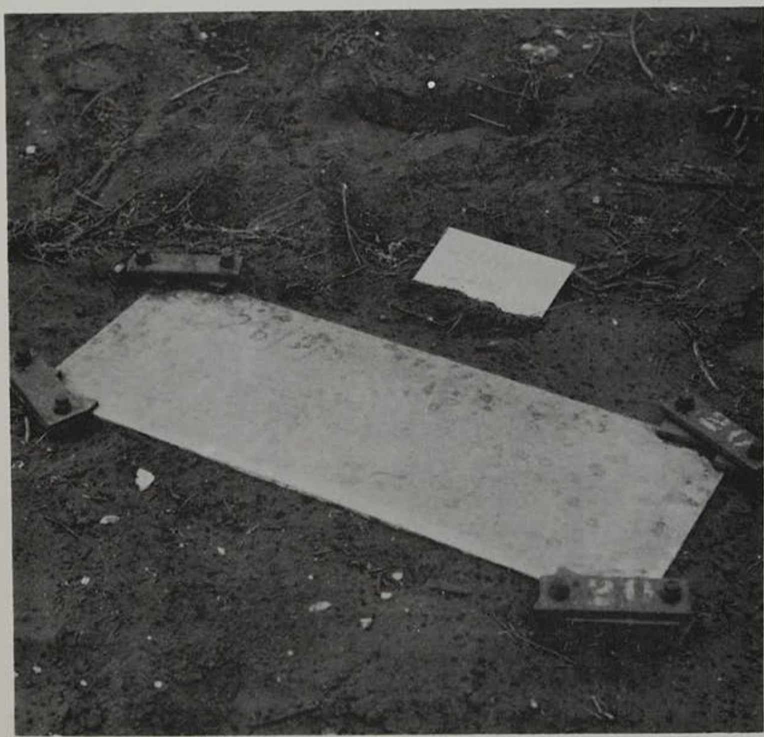


FIG 12 MODEL PANEL IN SURFACE BEFORE FIRING.

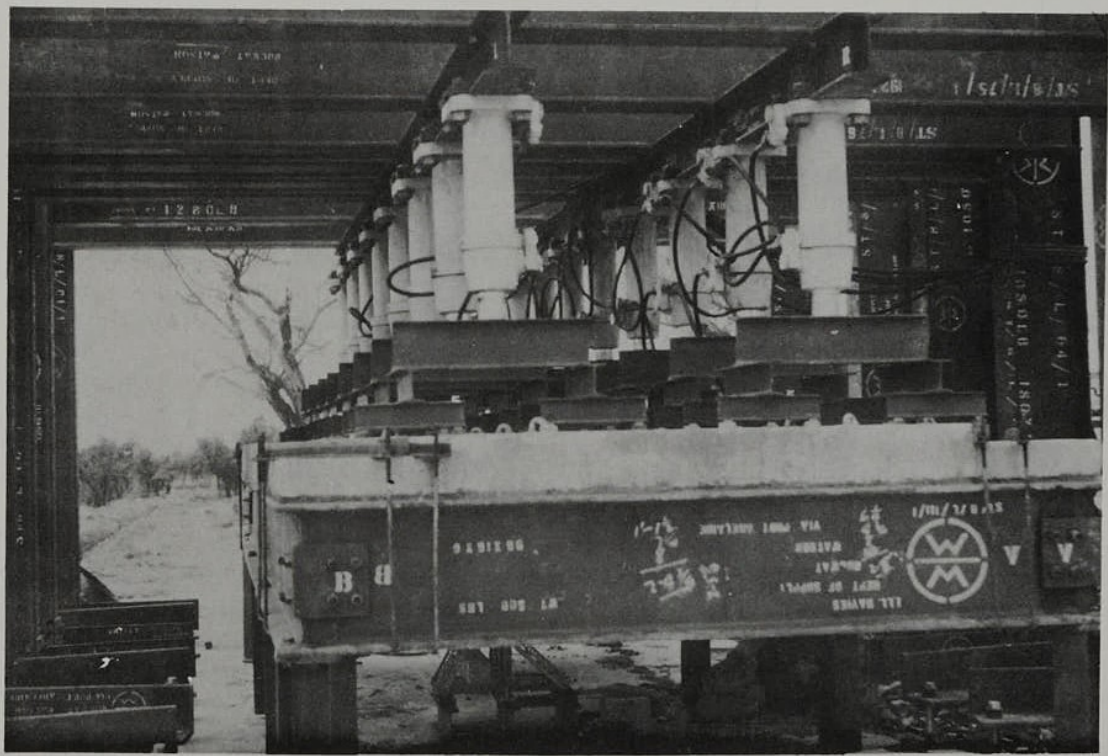


FIG 13 FULL SIZE PANEL SET UP IN TEST RIG READY FOR TEST.

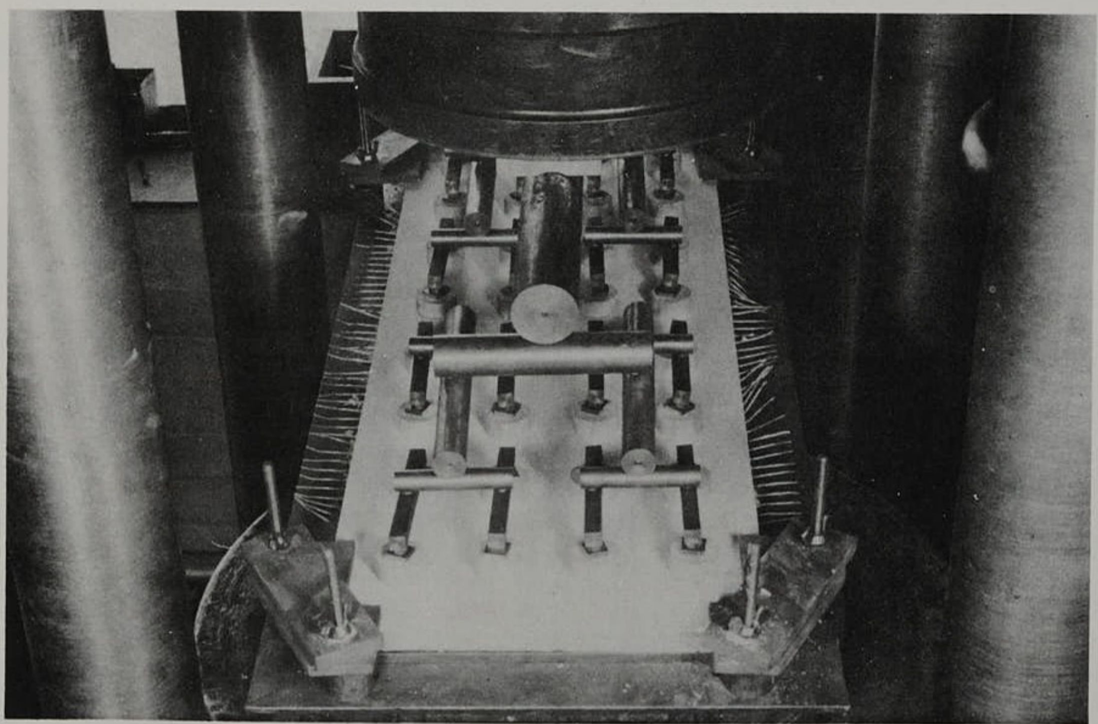


FIG. 14 PANEL READY FOR TESTING.

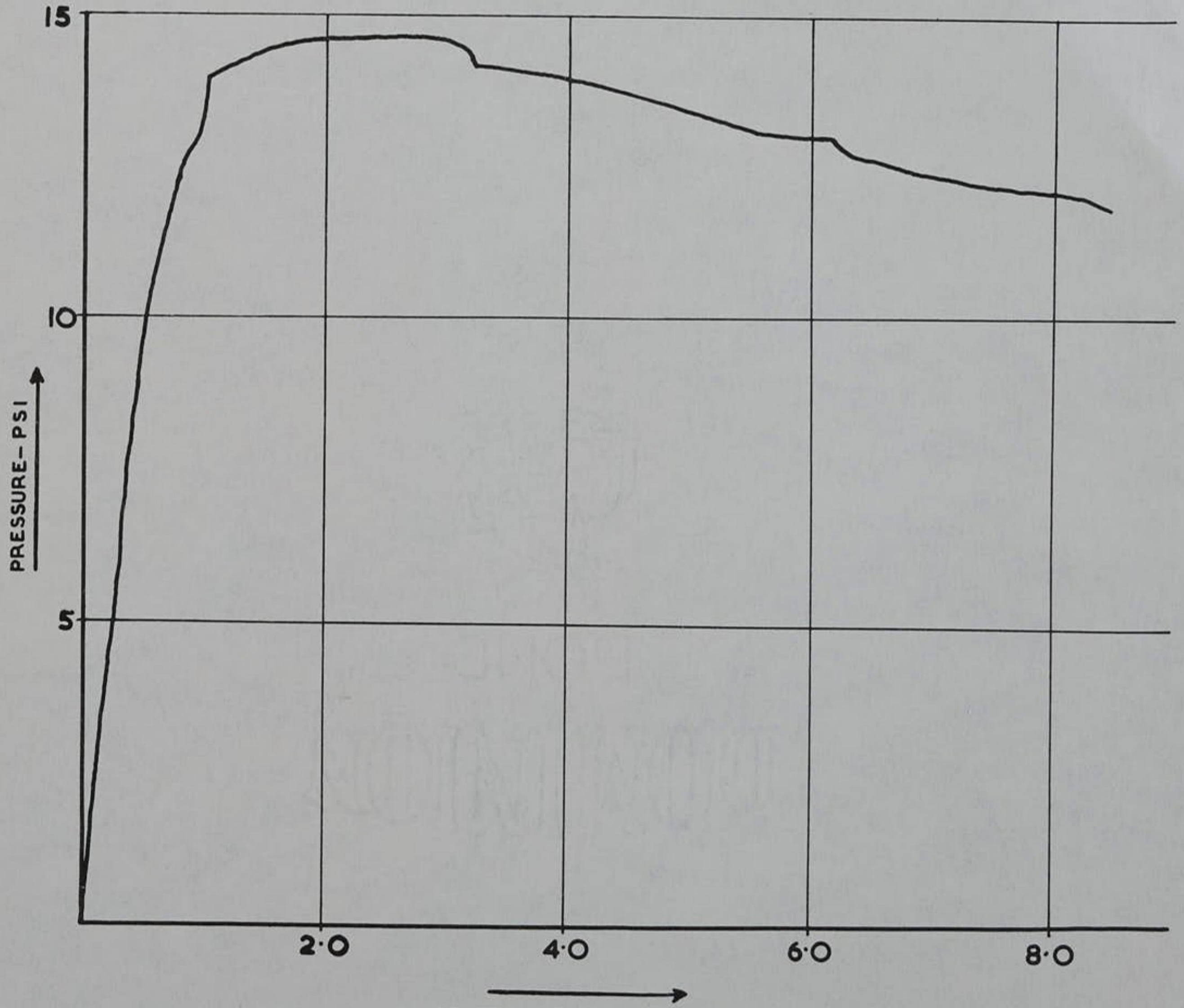


FIG 15 LOAD-DEFLECTION CURVE FOR FULL SCALE PANEL

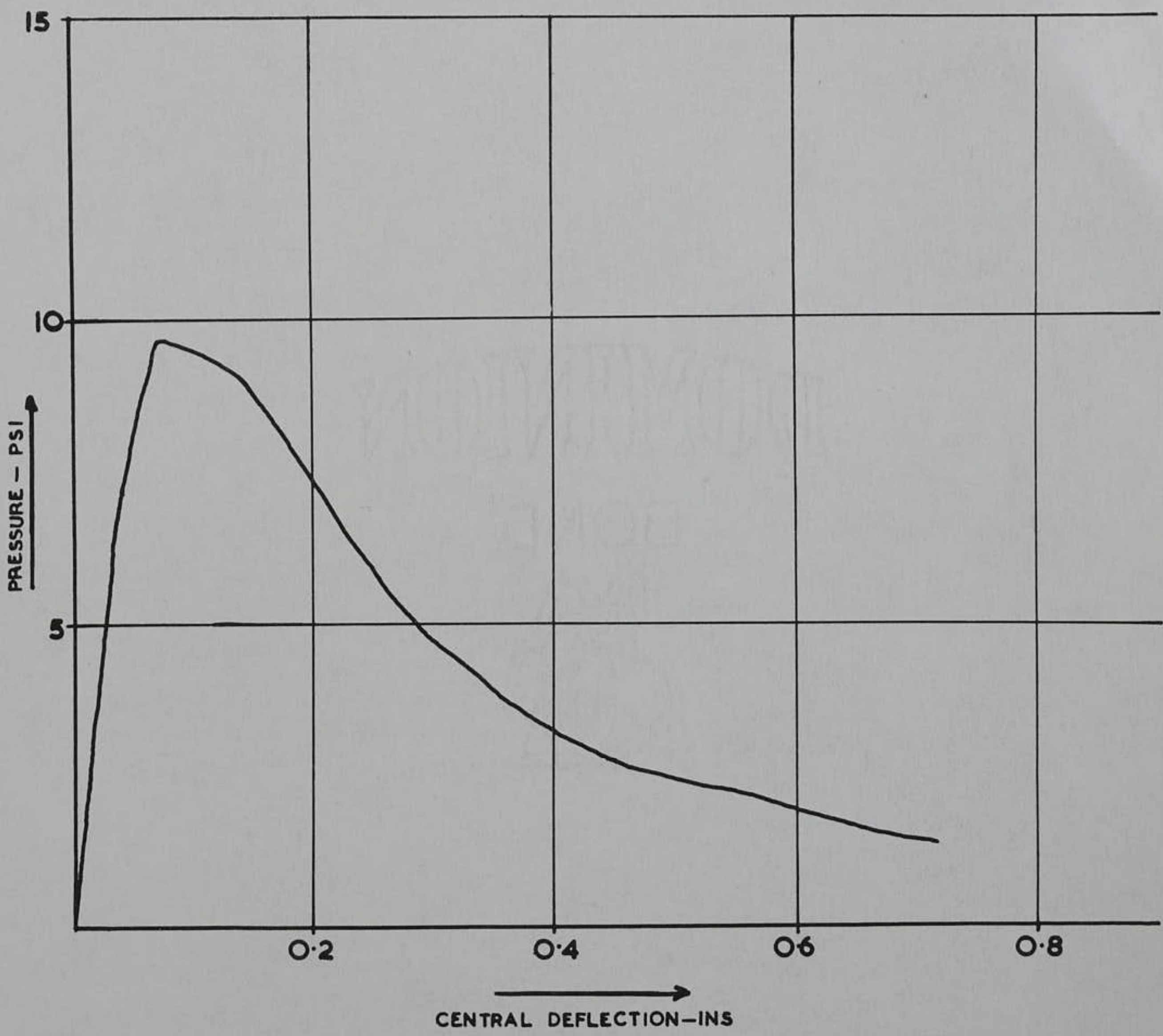


FIG 16 MEAN LOAD DEFLECTION CURVE FOR MODEL PANELS

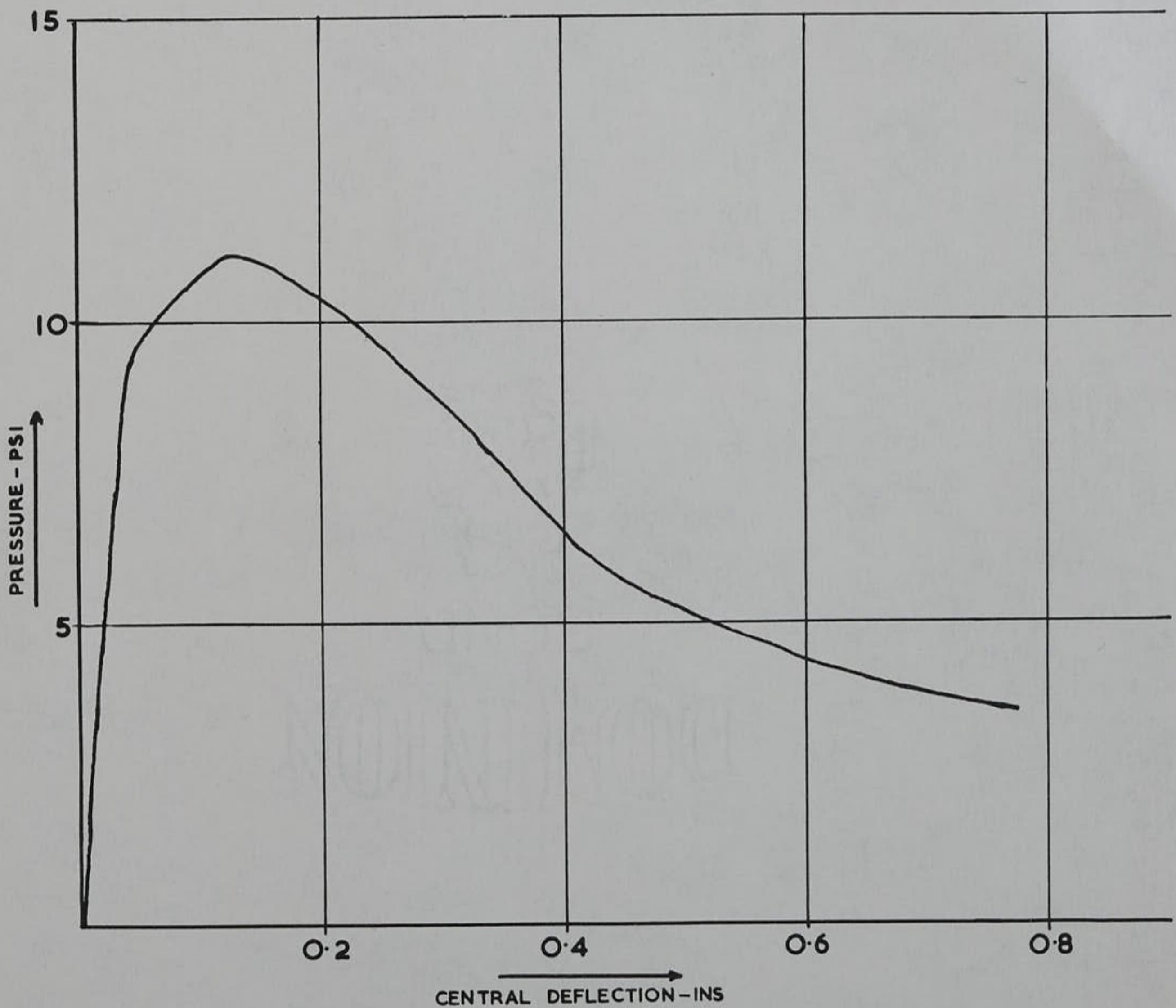


FIG 17. MEAN LOAD-DEFLECTION CURVE FOR MODEL PANELS CRACKED BEFORE TESTING

FIG. 18. DAMAGE TO FULL SCALE PANEL
AT 21·6 P.S.I.

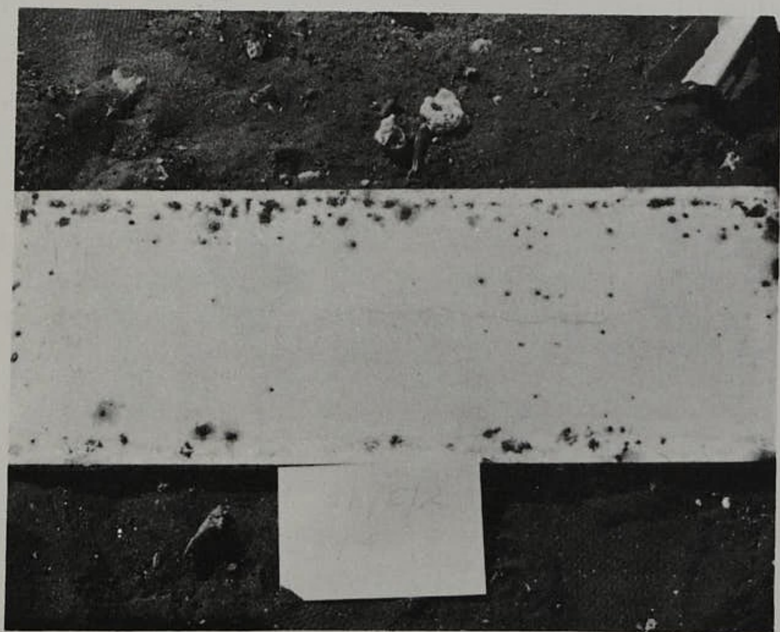
TOP

UNDERSIDE

FIG 19. DAMAGE TO MODEL PANEL WITH 6INS COVER

PRESSURE 17·9PSI RESIDUAL DEFLECTION 0·184INS

TOP

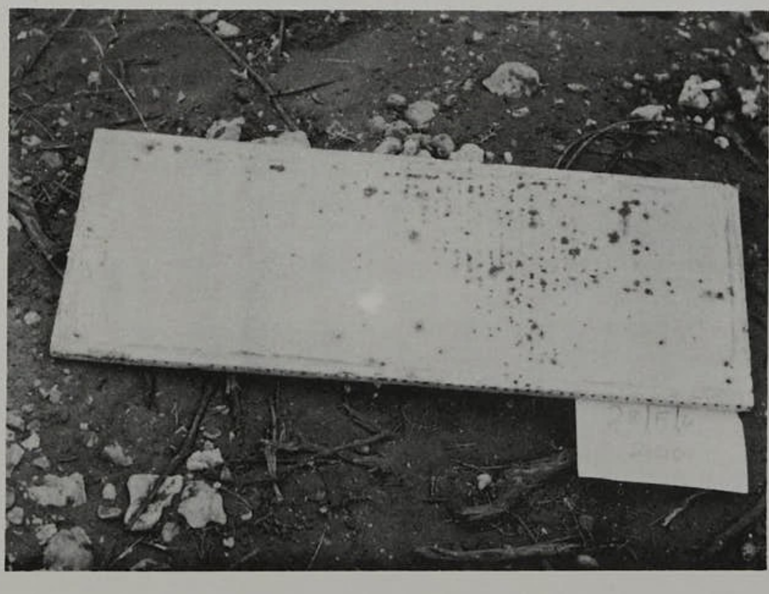


UNDERSIDE

FIG 20. DAMAGE TO MODEL PANEL WITH 6 INS COVER

PRESSURE 17·9 PSI RESIDUAL DEFLECTION 0·127 INS

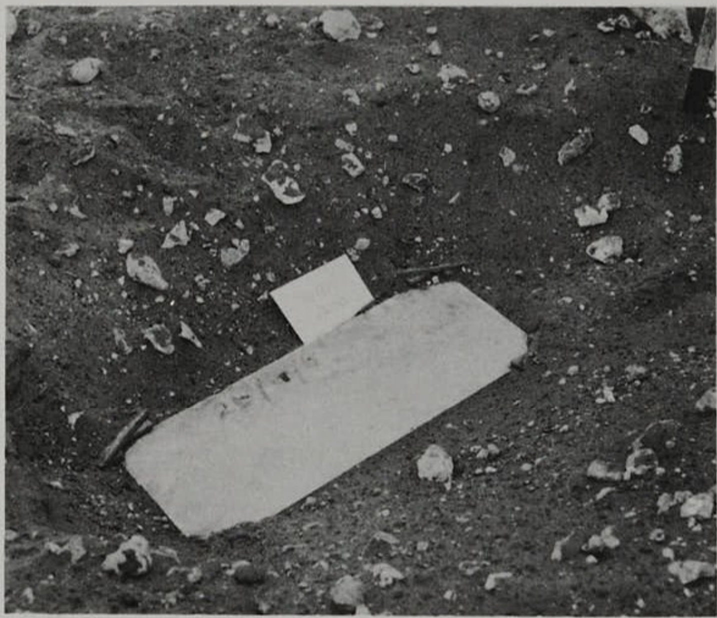
TOP



UNDERSIDE

FIG 21 DAMAGE TO MODEL PANEL WITH 6INS COVER

PRESSURE 13·2PSI RESIDUAL DEFLECTION 0·053INS

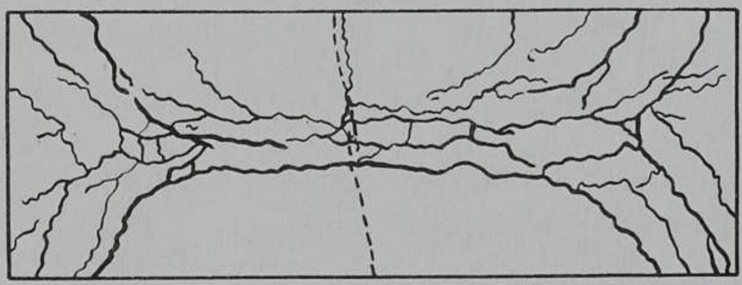


TOP

UNDERSIDE

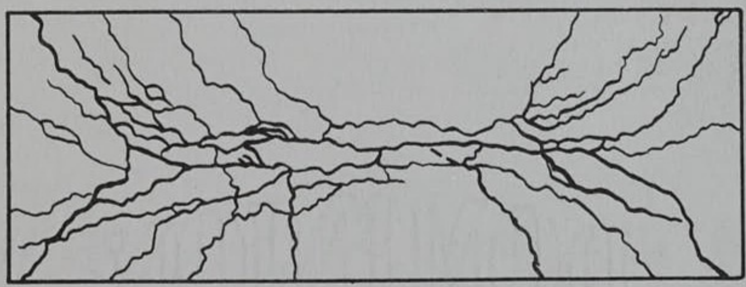
FIG. 22. DAMAGE TO MODEL PANEL WITH 12 INS. COVER

PRESSURE 12·0 PSI. RESIDUAL DEFLECTION 0·068 INS



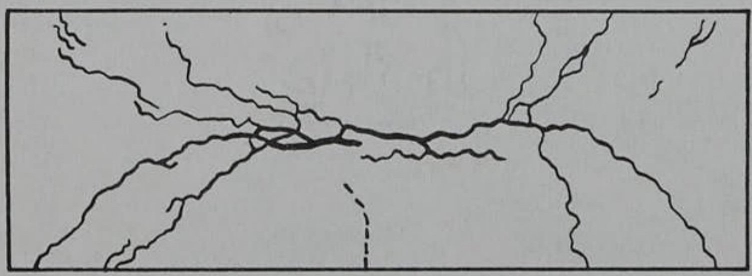
PANEL No 2a/A/2.

PRESSURE 27·0 P.S.I. RESIDUAL DEFLECTION 4·1 INS



PANEL No 2a/A/5

PRESSURE 17·9 P.S.I. RESIDUAL DEFLECTION 2·1 INS

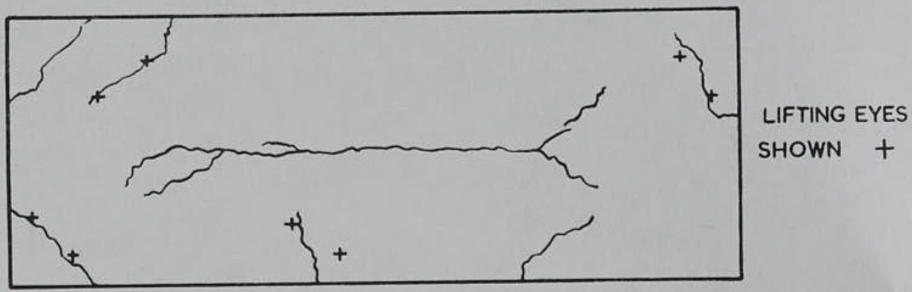


PANEL No 2a/A/7

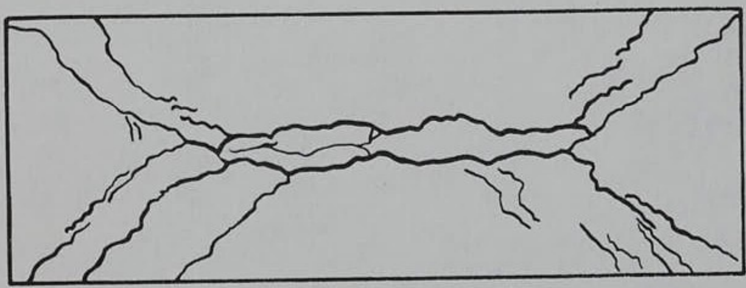
PRESSURE 12·0 P.S.I. RESIDUAL DEFLECTION 0·8 INS

FIG 23 CRACK PATTERNS ON UNDERSIDE OF FULL SCALE PANELS WITH 5 FT EARTH COVER AFTER FIRING.

BROKEN LINE SHOWS INITIAL CRACKING ON TOP SURFACES.



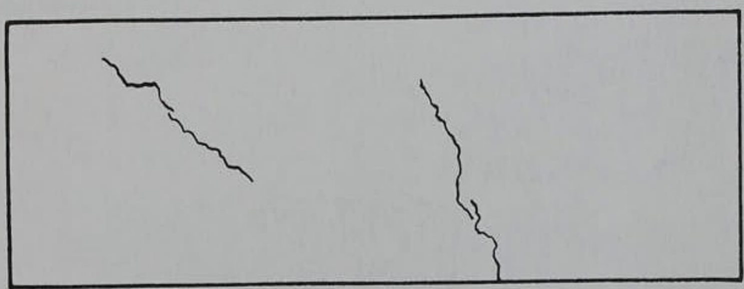
TOP.



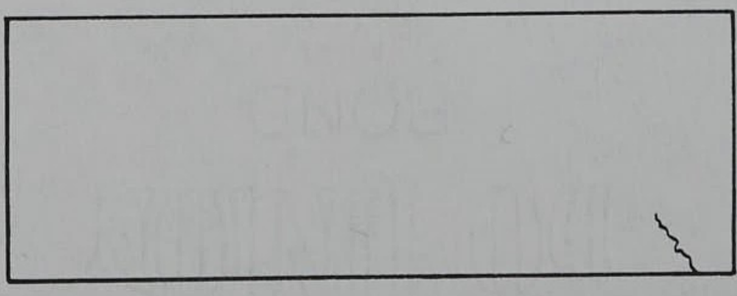
UNDERSIDE.

PANEL No 2a/A/6

PRESSURE 14·5 P.S.I. RESIDUAL DEFLECTION 0·9 INS.



TOP.



UNDERSIDE

PANEL No 2a/A/8

PRESSURE 10·3 P.S.I. RESIDUAL DEFLECTION 0·2 INS

FIG 24. CRACK PATTERNS ON FULL SCALE PANELS IN SURFACE AFTER FIRING.

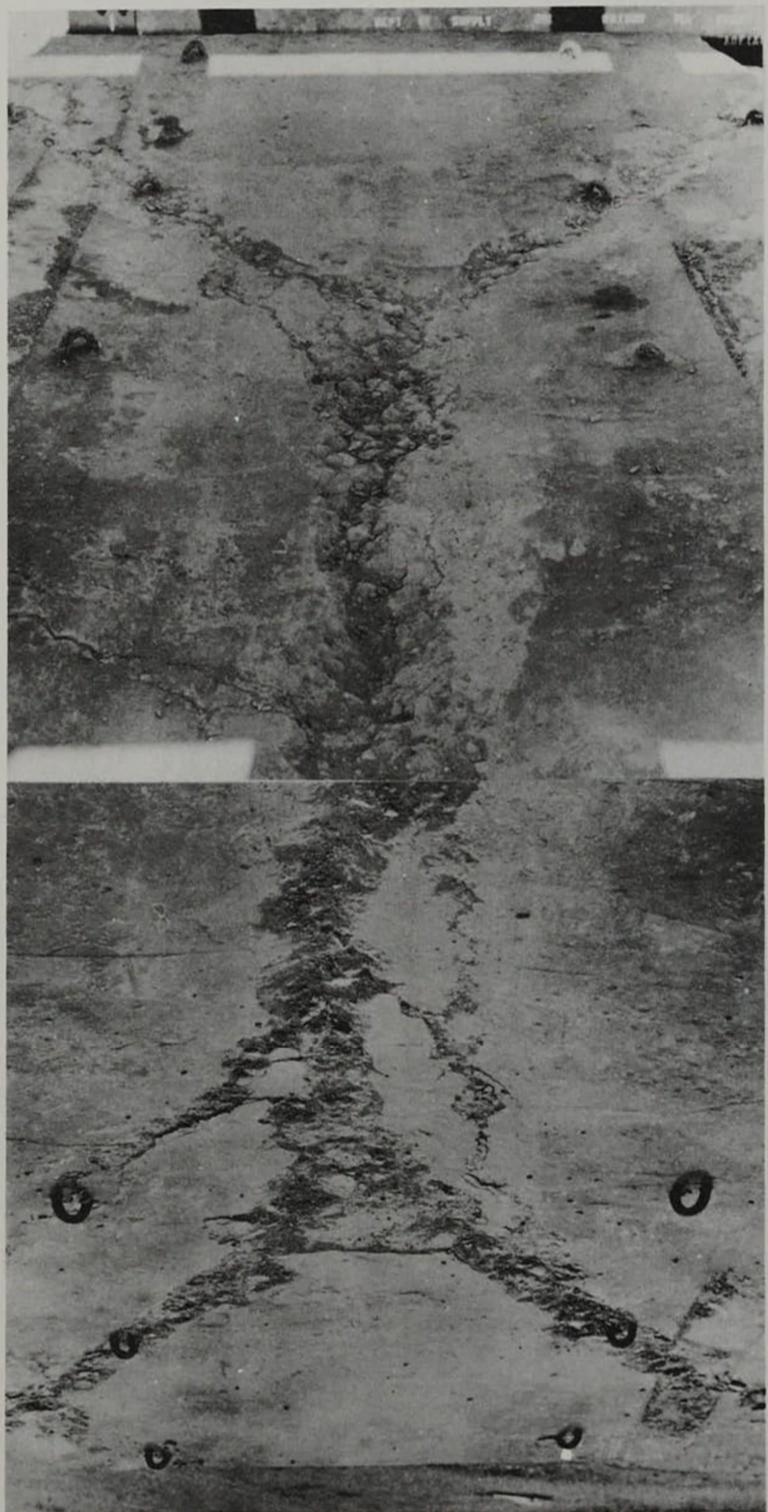
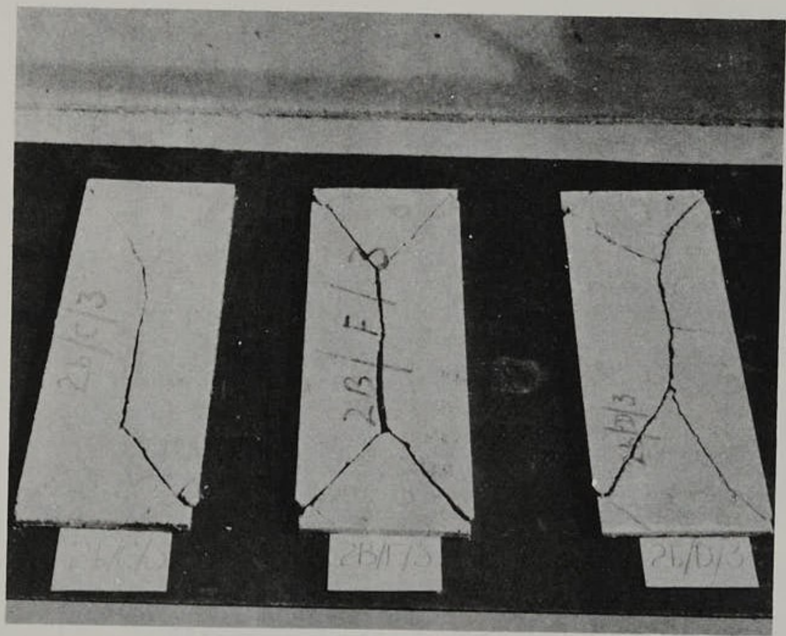
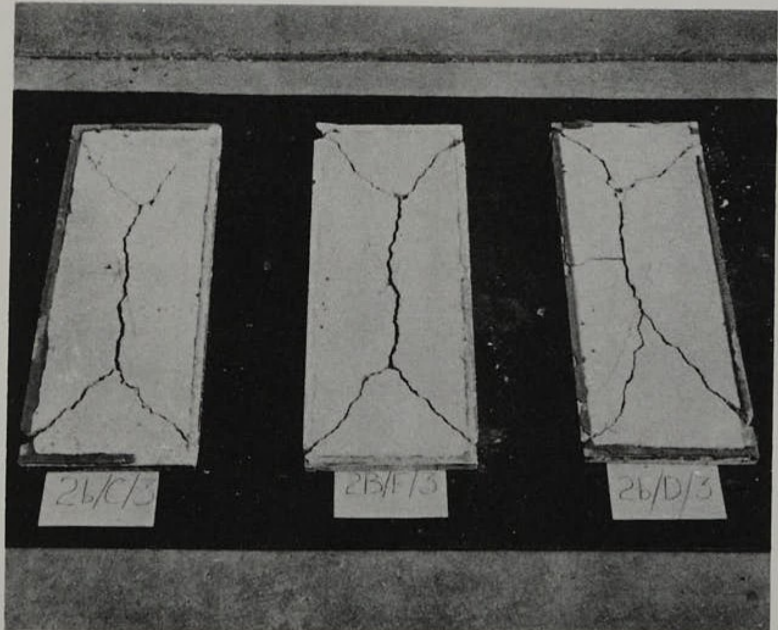


FIG 25. COMPOSITE PHOTOGRAPH OF TOP OF STATICALLY TESTED FULL SIZE PANEL



TOP



UNDERSIDE

FIG 26. TYPICAL DAMAGE TO MODEL PANELS UNDER STATIC LOADING

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